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THE USE OF ARTIFICIAL INSEMINATION FOR ANIMAL IMPROVEMENT IN THE UNITED STATES

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THE USE OF ARTIFICIAL INSEMINATION FOR ANIMAL IMPROVEMENT IN THE UNITED STATES

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INTRODUCTION

The principal feature of artificial insemination (AI) is that it enables an individual male to sire a very large number of progeny. The genetic implications of this can be understood by considering the theoretical expression for expected genetic progress due to truncation selection among potential parents on the basis of phenotype--

$$\Delta G = h^2 \; z/b\sigma_p$$

where ΔG denotes genetic gain per generation, h^2 is heritability in the narrow sense, b is the fraction of animals saved for breeding purposes, z is the ordinate of the normal curve corresponding to b, and σ_p is the phenotypic standard deviation.

Artificial insemination requires fewer breeding males, so there is an opportunity to increase the superiority of the males saved ($z/b\,\sigma_p$). This opportunity can be realized through accurate evaluation of the genetic merit of males and strict adherence to the goals of selection (yield, net economic worth, etc.) when choosing sires for extensive AI use.

The genetic value of artificial insemination must be assessed in relation to the standard of what is possible through traditional breeding systems employing natural mating. In most classes of livestock, the traditional breeding system is characterized by a group of "elite" pedigree herds that furnish the bulk of the breeding males for a much larger group of commercial and "multiplier" herds. Frequent two-way exchanges occur among the elite herds, but the relation of elite and commercial or multiplier herds is strictly one way. Therefore, considering the genetic improvement obtained through selection of males, progress for the entire population is tied to what occurs in the small group of elite herds.

Theoretical comparisons between AI and natural service breeding systems were made by Rendel and Robertson (24)[2] and Robertson and Rendel (26). They found that the maximum expected gains would be about

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2/ Underscored numbers in parentheses refer to Literature Cited at end of this report.

1 percent per year for closed herds and 1.7 percent per year for an AI system (2,000 females). These expectations were in the framework of improvement in milk yield of dairy cattle through the selection of bulls on progeny test results. Rendel and Robertson pointed out that the continuous introduction of unknown genes from outside the AI unit is detrimental to genetic progress. To have a lasting impact, the superior AI bulls must pass on their genes through their sons as well as through their daughters. Otherwise, the genes of the best bulls are diluted in the next generation by the influx of new genes from foreign bulls of unknown merit. This theoretical expectation is being borne out in the development of AI in dairy cattle in the United States. Only where those responsible for AI have pursued sound independent breeding programs has more rapid genetic improvement resulted.

In order for AI service to exert a favorable genetic influence, it is necessary to make accurate choices among the males that are available. The first requirement is that an organized performance testing program be practiced. For most classes of livestock and poultry, performance testing is practically nil, ranging from about 95 percent in turkeys to a mere scattering in sheep. An interesting feature is that the scope of performance testing required for AI is actually less than that required for natural service. All that is required is the testing of enough AI herds to evaluate the progeny of the current crop of stud sires and to supply young sires for entry into future progeny tests. All other herds using AI indirectly receive benefits of testing through the AI service. Nevertheless, in the United States the scope of testing in some classes of livestock is too small even to support AI effectively.

The performance testing data used may be either information on the daughters (or other relatives of the sire), on the sire himself, or a combination of both. In the improvement of carcass traits or of such a sex-limited trait as milk yield in dairy cattle, some form of family selection must be practiced.

The chief form of family selection is the progeny test. The principal disadvantage of the progeny test is that it may increase the generation interval and thereby slow the rate of progress per year. The test results may accrue so slowly that many of the sires involved are dead by the time the data are collected. Where progeny testing is required, AI service has an added advantage over the the traditional breeding program. In dairy cattle, for example, many herds are too small to use more than one bull at a time. In such a case no true selection among sires is possible. As a practical matter, most of what has been called progeny testing in dairy cattle has been in reality sib testing, i.e., young bulls were chosen for use on the basis of how their paternal sisters performed.

Robertson and Rendel (26) described an optimum AI system for progeny testing to improve a sex-limited trait-milk yield in dairy cattle. This system consists of (1) progeny testing a large group of young bulls on a portion of the cow population, (2) restricting service from these bulls as they await the evaluation of the test, and (3) selecting for heavy use bulls that proved superior by the progeny test results. They found that the number of breeding females in the AI unit had a key influence on genetic progress, whereas the heritability of the trait under selection had relatively little influence on the optimum breeding plan. The latter point indicates that AI has advantages even for traits that are relatively highly heritable. The small size of closed herds is the principal reason that this type of breeding system is disadvantageous.

Dunlop and Young (7) evaluated theoretically the relative merits of natural and AI service for wool improvement under conditions appropriate to Australia. They concluded that AI was superior by a margin of 18 to 26 percent, depending upon the conditions. Given a flock of 1,000 ewes or less, they estimated that natural service would yield more rapid progress than AI service, mainly because of the depressing effects of inbreeding that would result from the use of a small number of rams.

Experience with dairy cattle has disclosed another problem whose solution is more easily obtained through artificial service than through natural service. The early results of AI showed that the performance of a bull's daughters in a single herd was not an accurate indicator of the performance of his artificial progeny in a random cross section of herds. Research has shown that this difference in accuracy results from the high environmental correlations that exist among progeny in the same herd and time period. Therefore, the AI progeny test is the only accurate means of evaluating bulls for use in a variety of herd environments. Similar situations may be anticipated for other classes of livestock.

Crossbreeding may be a useful breeding procedure through which performance can be improved in some classes of farm animals. In such cases, the crossbreeding plan can be carried out somewhat more readily by use of artificial insemination because the need for each herd to maintain males of two or more different breeds is eliminated.

A possible genetic drawback to AI is that the rate of inbreeding may increase if only a few males are used to inseminate the entire population of females. This has two effects: (1) An immediate depressing effect on performance, and (2) a long-term reduction in genetic variation (heritability). Robertson (25) estimated that inbreeding would increase at a rate of 2.4 percent per generation if two males are used to produce future sires and 12 males are used to sire the females for production purposes. In reality, the inbreeding problem is more acute for the strictly closed-herd situation where the number of animals is small. O'Connor and Willis (23) reported that inbreeding was higher in naturally sired British Friesian cattle than in artificially sired animals. Only

the periodic introduction of outside genes can reduce inbreeding in a closed system. There appears to be no serious problem at present for the larger AI units and the more numerous breeds of dairy cattle.

Considering the national population as a whole, there has been some debate as to the optimum structure in terms of the number of AI units and their interrelationships. As Wright (36) advocated, splitting the total population into several independent units would lead to genetic diversity among the separate groups. In this way more flexibility is available in the event of (1) dangerously high inbreeding accumulation, or (2) selection plateaus in the individual groups. In order to produce such a structure, it is necessary to limit the exchange of genes among the different AI units, which is likely to be rather difficult in view of the experience with dairy cattle.

An additional genetic disadvantage sometimes ascribed to AI is that the frequency of deleterious recessives might be increased. This appears to be an untenable argument. In the first place, only genes already present in the purebred population can be spread. In the second place, males that carry unfavorable recessives are much more likely to be detected in AI than in natural service because of the greater number of offspring. A further advantage for AI is that if a natural service herd has one carrier cow it is likely to have several, because fewer individual sires are used in natural service herds.

Certain nongenetic advantages may be cited for the use of artificial insemination. In some instances, the spread of disease may be controlled more effectively through the use of AI. This is an especially important consideration in swine but is of no importance in poultry. An advantage that applies to dairy cattle is the elimination of a safety hazard on farms that maintain bulls for natural service. A final advantage is that physically difficult or impossible matings in natural service may be carried out by artificial means. Examples are the use of old, infirm, or even dead males or the mating of large males to small or immature females. Interspecific matings may be carried out artificially for research applications, as for example, the cross of Coturnix quail with domestic poultry.

Certain nongenetic disadvantages of artificial service are occasionally mentioned. The first is that conception rates may be decreased and are less likely to be higher than those in natural service. The second is that production costs may be increased because of the added insemination expense and labor requirements. A third disadvantage where professional inseminators are utilized is the possibility that AI technicians may spread infectious diseases from farm to farm. Experience with dairy cattle has shown that the latter is not a serious problem.

A spurious argument occasionally used is that individual breeders would lose control of their breeding programs by relying on AI. This is a groundless objection because breeders still would have a relatively wide selection of sires available for artificial service. Furthermore, the knowledge of the transmitting ability of males in artificial service would be much more complete than that for any possible selection of sires in natural service.

At present, there is a wide disparity in the adoption of AI among different classes of livestock in the United States. The reasons for this are both economic and biological. It is safe to say that the physical process of artificial insemination is now feasible for all classes of livestock and with reasonably satisfactory conception rates. In most cases, however, the conditions required for satisfactory service are not economically practical. Except in cattle, insemination must be done with fresh (nonfrozen) semen. This is a problem, especially where the population of flocks or herds is widely dispersed and semen has to be transported long distances. The lack of means of freezing semen is a serious drawback for sheep insemination.

A second problem is that of heat detection. Husbandry conditions for beef cattle and sheep in the United States often make close observation of individual animals economically impractical, especially in the large flocks and herds on the western ranges. This barrier will be overcome only when economically practical methods of estrus control are perfected. When the onset of estrus can be accurately and economically regulated in large flocks and herds, artificial service is likely to increase rapidly in sheep, beef cattle, and swine.

Other obstacles to the adoption of artificial insemination are purely economical. They are (1) the low density of the animal population in many areas, (2) the low value of individual animals, and (3) the small size of herds and flocks. The rapid spread of dairy cattle AI is partly due to the high density of dairy farms in many areas, the high monetary value of the individual cow, and the steady increases in herd size. Under these conditions it has been economically feasible for professional inseminators to visit herds for single-cow services. Where the farms are widely dispersed and herd sizes are small, the cost of artificial service increases. The trend in the United States is toward increased herd size, so that more inseminations can be made by an inseminator per mile traveled. This will lower AI costs, especially where farm personnel can be trained to carry out the service successfully.

CURRENT STATUS IN DAIRY CATTLE

Most of the experience in the practical application of artificial insemination in the United States comes from its use with dairy cattle. In the beginning, AI service was merely an appendage of the traditional pedigree breeding system because artificial service was used very little in the elite herds, and the bulls for AI largely came from these herds. Purebred breeders initially regarded AI unfavorably because they believed it would threaten the sales of purebred bulls to commercial herds. This resistance gradually receded over the years. In 1966, 48 percent of all dairy cows and heifers were bred to artificial service, reflecting an essentially linear trend over years (fig.1). About 12 percent of the inseminations represent registered cows.

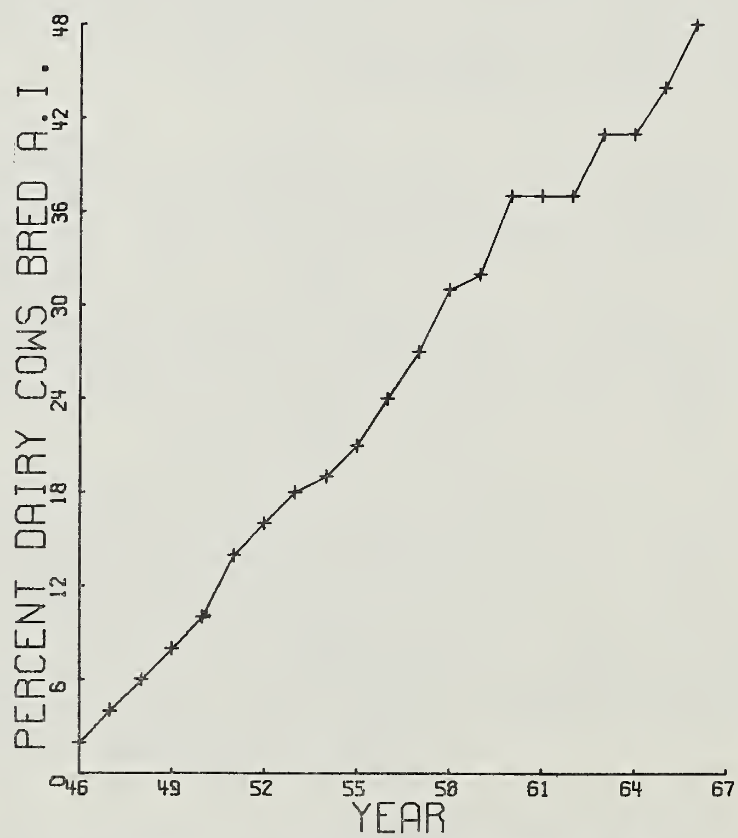

FIGURE 1. TREND IN PERCENT OF U.S. DAIRY COWS AND HEIFERS BRED BY A.I.

AI has been received favorably, especially among commercial dairymen, for three reasons. First of all, conception rates from AI have been satisfactory, even after the use of deep-frozen semen was adopted. Elliott (8) reported that semen giving a 70.8 percent nonreturn rate in liquid form (20,526 services) gave a 71.9 percent nonreturn rate when frozen (15,721 services). Hansel (15) reported that the 60 to 90 day nonreturn rate in New York has risen from 61 percent to 75 percent since 1950. In 1956 Herman (17) reported the results of a survey of 12 AI units that had a total of 794,221 first services. The average 60 to 90 day nonreturn rate was 72 percent (fresh semen).

A second reason for the adoption of dairy AI is that family selection is required in the selection of bulls because no direct measurement of milk production is possible. Progeny testing is a very time-consuming and costly process. Facts are that AI has made progeny testing possible and practical. In single herds of conventional size, a breeder cannot have an adequate number of daughters to assess each bull and at the same time test enough bulls to provide an opportunity for selection among bulls. In other words, the natural service progeny test data were used for sib-testing purposes. AI programs, as described by Robertson and Rendel (26), make genuine progeny tests possible. The value of AI in progeny testing has been advanced through the educational efforts of the Agricultural Extension Service.

A third reason for the adoption of artificial service is that the purebred dairy organizations generally have assumed a more constructive attitude toward the registration of AI progeny than have corresponding groups in some of the other classes of livestock. Although many purebred breeders initially looked upon AI with disfavor because of its threat to bull sales, the conditions established for registration generally have not been restrictive. In 1965, 69.2 percent (177,790 head) of all Holstein cattle registered in the United States were sired artificially (21). In that year 36 sires had from 800 to 2,771 female offspring registered. One bull alone accounted for 1.18 percent of all females registered in 1965. Another bull sired 2.4 percent of the males registered. As of January 1, 1966, one sire had a total of 19,459 registered progeny; four other bulls had over 14,000 each.

Although artificial service has reduced the number of males registered and kept for breeding use, no movement toward the use of nonregistered bulls in AI has ever occurred.

The organizational structure of AI units in the United States consists of three large private organizations and about 30 farmer-owned cooperatives. Cooperatives account for about two-thirds of the total AI

services. The trend has been toward consolidation of studs: 97 different organizations existed in 1950. Consolidation results from the need to economize in the housing of bulls and in the processing, storing, and distribution of semen. Prospects are that this trend will continue. In addition, some AI units have agreed to cooperate in the use of bulls of the rarer breeds. For example, less than half of all studs maintain their own Ayrshire bulls at present. In general, the trend is toward less genetic isolation of the different AI units.

AI service is technically available in all areas of the Nation, but it tends to be more concentrated in the high density dairy regions. The highest rate of AI service (as a fraction of the total dairy population) is in the Northeast and upper Midwest, whereas the lowest is in the South and Southwest.

In the cooperatives, bull selection policies are guided by "sire committees" made up of member dairymen and one or two members of the cooperative management staff. Generally, there is a separate committee for each breed. These committees frequently draw upon university research workers and dairy extension leaders for advice. Considerable effort is spent in visiting patron herds to inspect progeny for possible bull purchases. These committees in effect determine the course of genetic progress for their patrons.

The cooperative units are generally aware of the importance of performance testing to the selection of bulls, and many have actively encouraged the growth of testing in their areas. However, no monetary discounts are provided to production-tested herds that use artificial service.

DHIA performance testing results are compiled for the various progeny groups by the U.S. Department of Agriculture. The herdmate comparison method is employed to obtain estimates of the transmitting ability of each bull relative to the breed as a whole. Each bull's deviation of progeny from herdmates is weighted by taking into account heritability, number of progeny, and distribution of the progeny over herds. These evaluations are published and made available to the AI units and to individual breeders.

In the early stages of artificial insemination, bulls were purchased on the basis of natural-service proofs made in individual bull-breeding pedigree herds. Only rarely were bulls sired by earlier AI sires put into artificial service. Although no national assessment of the impact of AI has ever been made, scattered evidence indicates that actual genetic progress was less than had been anticipated during this period. Van Vleck and Henderson (31) studied New York Holstein data over a 10-year period and found that AI progeny had an advantage of 197 pounds of milk over their naturally sired herdmates. In Wisconsin

for 1951-56, Corley, Duckwall, and Heizer (5) found an advantage of 238 pounds of milk for AI Holsteins within the same herd. Wadell and McGilliard (32) found an AI superiority of 124 pounds of milk in Michigan Holstein herds. Hahn, Carmon, and Miller (14) found that naturally sired herdmates were actually superior to their AI herdmates in Georgia herds during the period 1951-56. Tucker, Legates, and Farthing (29) found an advantage of 322 pounds of milk for AI progeny in North Carolina. All of these studies suffer from the disadvantage of having failed to express genetic gain relative to the entire population. More recently, Harville (16) found a yearly genetic trend of 104 pounds of milk in New York Holstein herds that used artificial service.

Because of the disappointing earlier results, a number of AI organizations altered their sire procurement policies and now evaluate young bulls on the basis of AI proofs, rather than on the results of prior natural service. The New York Cooperative was the first unit to adopt a program similar to that described by Robertson and Rendel (26). More recently, American Breeders Service, a private organization breeding over 1.25 million cows annually, has also adopted a similar program for the Holstein breed. Currently, 60 to 70 new bulls are entered in the progeny testing program each year.3/ The progeny of the first young bulls placed on test are now being evaluated. As of July 1967, the stud was holding approximately 300 young bulls awaiting progeny test results. Unlike most other progeny testing situations, this organization tests its bulls in special "Associated Herds." These are DHIA tested herds that agree to mate at least 30 percent of their cows to young bulls, in return for special privileges in obtaining service of proven bulls in the stud.

Bayley (2) surveyed 31 AI units to determine their bull procurement policies. Seventeen of these units had plans for establishing programs to sample young bulls artificially. Experience thus far indicates that some organizations fail to sample enough bulls to obtain a satisfactory selection differential. Also, young bulls are sometimes retained to service beyond the required sampling period.

Many AI units do not service enough cows to justify the costs of sampling bulls. Van Vleck (30) estimated that the cost of sampling one bull was $2,000. This figure is now probably too low. In addition, few if any units breed enough Ayrshire or Brown Swiss cows to permit AI sampling. Further research is needed to assess the merits of the alternative of sib testing with rapid turnover of bull batteries. Indications are that storage costs may be reduced by deep freezing a large supply of semen from each young bull and then disposing of the bulls.

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3/ Personal communication from R. Walton.

The most promising aspect of AI today is the increasing determination of various units to formulate plans for breeding improvement, rather than to rely solely on individual breeders to make the matings for new sires and to progeny test the bulls. Today many studs are actively contracting with dairymen to mate outstanding cows to the best AI proven sires in order to provide a source of bulls for progeny-test programs. As a result, the selection differentials on bulls entering progeny test schemes should be greatly increased.

None of the AI units make a concerted effort to progeny test bulls for harmful recessives by back-crossing bulls to their daughters or mating them to known carrier cows. Falconer (11) has suggested that bulls selected for heavy service in AI should be mated to a sample of their daughters to increase the chances of detecting carrier bulls. If a bull sired 1,000 daughters by a random selection of cows, the presence of any recessives with frequencies of 1 percent or greater could be detected. Genes with lower frequencies would require test matings for detection. Bulls identified as carriers would be removed from the stud, and none of their sons would be used for AI service. At present the AI industry in the United States relies on the reporting of abnormal offspring by inseminators and dairymen.

In contrast to European practices, relatively little attention is paid to traits other than yield in selecting sires for AI service. Generally, the bulls are classified for conformation, and the type of their progeny is spot checked on a subjective basis. The official DHIA progeny test summary provides information on milk yield, fat yield, fat test, and the proportion of first-calf daughters that were culled from the herd. At the present time there has not been sufficient economic incentive to obtain progeny test information on total solids or protein.

Although there are many different AI groups, the artificial herds within a breed effectively form a single population because of the frequent exchanges of genes among the different units. This occurs because the studs frequently purchase sons of bulls used in other studs and because semen is frequently exchanged directly among the cooperatives. Also, many herds alternate in receiving service from two or more studs. For these reasons inbreeding and decreases in genetic variance have not yet become serious problems. Table 1 shows the number of bulls and total cows served for the various breeds in 1966. This table indicates that the situation in Ayrshires (only 42 sires) needs to be watched carefully in the future. Also, individual bulls may be used disproportionately, thus further reducing the effective number of sires in the breed. For example, the Ayrshire bull Selwood Betty's Commander has been used very heavily due to this extremely high daughter superiority (+1,800 lb.). At present this bull has more than four times as many tested progeny as any other Ayrshire bull with daughters currently in milk.

TABLE 1.--Number of bulls in service and cows served by AI in 1966

Breed	Bulls	Estimated cows serviced
	Number	Number
Ayrshire	42	130,000
Guernsey	278	640,000
Holstein	1,352	5,070,000
Jersey	220	450,000
Brown Swiss	90	130,000

The outlook for dairy AI in the United States is a continued increase in the proportion of the population inseminated, as the size of herds increases. The adoption of AI will be aided if the progeny test programs now in progress accelerate the rate of genetic advance. Estrus control would have some favorable impact, although not to the degree in other species.

CURRENT STATUS IN BEEF CATTLE

The current application of artificial insemination in beef cattle has been discussed by Gregory (13). In general, the adoption of AI by commercial beef cattle breeders has been very slow. The number of beef cows bred artificially for 1963-66 is shown in the following tabulation:

Year	Beef cows bred artificially
1966	647,143 1/
1965	615,147
1964	464,959
1963	235,289

1/ Represents about 2 percent of the total beef population.

At present most of the beef cattle service is provided by the dairy AI units. Twenty-nine studs reported a total of 364 beef sires in 1966. Currently, more dairy cows (873,127) are served by these bulls than beef cows.

The relatively low saturation of artificial service is due to a number of causes. From a strictly technical standpoint, artificial insemination can be accomplished successfully in beef cattle. The inhibiting factors involve mainly economic and husbandry conditions. Most feeder calves are produced in western and southwestern United States where range conditions are characterized by very large holdings and large ratios of cattle per worker. Under these conditions, the structure characteristic of dairy AI is impractical. Inseminators would be required to travel great distances to make their calls in these areas. Gregory (13) surveyed 23 users of AI in Nebraska and found that only four used professional inseminators. The majority of these users carried out the insemination themselves, a procedure that requires adequate semen storage mechanisms on the ranch. In addition, the cattle are so widely dispersed that they may not be checked for days at a time, thus increasing the difficulty of adequate observation of heat.

An additional factor that influences the use of AI for many herds is the restrictive policy of purebred organizations regarding the registry of artificially sired calves. A summary of these policies has been published by the National Association of Animal Breeders (22). In general, the requirements are that the sire and dam of a calf must be owned by the same person, but the sire may be owned by a number of parties usually not exceeding five. These regulations discourage the general use of AI in registered herds. The registry groups are attempting to maintain markets for registered sires at the cost of limiting the use of a powerful tool for genetic improvement.

A third factor is that progeny testing is somewhat less critical in beef cattle because some of the more important traits (e.g., rate of gain) can be measured on the males directly. With performance testing a breeder can assess the genetic merit of several bulls in his herd when choosing bulls for breeding use. However, the use of progeny tests and family selection can increase the accuracy of choices among bulls. In addition, measuring a bull's transmitting ability for maternally influenced traits and carcass characteristics requires a progeny test or sib test. In any case, the selection differentials that can be achieved give artificial service an advantage over any system involving individual herd sires. Warwick (33) estimated that optimum use of AI could speed improvement in carcass traits, weaning weight, and rate of gain by 300, 200, and 50 percent, respectively.

On the basis of experience with dairy cattle, it can be assumed that improvement through sire selection requires less performance testing in artificial insemination than in natural service. Producers not enrolled in performance testing can use AI bulls that were progeny tested in other herds. This may be an important consideration in the improvement of range herds.

The future of AI in many commercial herds, particularly the smaller units, depends largely on the development of methods of estrus control that allow reasonable conception rates. Considerable research is being performed on this problem in the United States. Hansel (15) studied the effectiveness of oxytocin and progestational compounds for the control of estrus. A combined oxytocin-progesterone treatment controlled estrus in 26 of 27 Hereford heifers and resulted in a 50 percent conception rate. Hansel concluded that bovine estrus cycles can be successfully controlled by feeding 6-methyl-17-acetoxprogesterone for periods of 20 days. He indicated that conception rates of 50 to 60 percent are currently possible. Anderson Ray, and Melampy (1) reported satisfactory cycle control and 55 to 60 percent conception rates through the use of progesterone derivatives.

Estrus control in cattle holds great promise for the expansion of beef AI. Further research in methodology, embryonic mortality, and possible side effects is needed.

CURRENT STATUS IN SWINE

Artificial insemination has had very little practical impact on commercial swine production in the United States. In 1966 only 5,267 animals were inseminated through commercial studs. These services were provided by two dairy studs in Wisconsin and Illinois. Because of the lack of satisfactory means of deep freezing boar semen, all services were on a fresh semen basis.

The lack of a satisfactory procedure for freezing sperm has not been the most serious handicap. The two studs operating in swine at present are located in areas that have a very high density of herds producing feeder pigs. Where there is a relatively high density of swine and semen does not have to be transported great distances, such service can be provided by inseminators as a supplement to their work with dairy herds in the same area.

The principal hindrance to adoption of swine AI is the cost of the service. The relative cost of insemination is rather high where an inseminator visits a herd to make only one or two services, especially where free repeat service is provided if the first service is infertile. Such a practice is economically feasible in dairy cattle because of the great value of the individual animal. The cost is especially high if swine herds are widely dispersed. Transportation costs are also increased

by the necessity of shipping a new supply of fresh semen from the stud boars each day. If controlled estrus becomes biologically and economically feasible, swine AI will become a greater factor in breeding improvement.

Cost of providing AI service may also be increased by lowered conception rates. Commercial results indicate conception rates and litter sizes of 74 percent and 9 pigs for sows and 71 percent and 8 pigs for gilts, according to Young (37). In general, conception rates seem to be adequate if farmers are accurate and prompt in diagnosing estrus.

The direct costs of service may be lowered by training herd owners to carry out the insemination. About 70 percent of the swine service in Illinois is done by farmers (18). The average conception rate on first service is about 65 percent. Semen costs the farmer only about $2 per ampule, whereas inseminator charges would amount to about $5 for first service and $2.50 for repeat service. Even if the owner performs the inseminations, he still must pick up a supply of semen from the stud each day.

What is the potential for improvement of swine through AI service? At the present time, the level of performance testing is very low in commercial swine herds. What improvement is made through mass selection largely comes from grading-up through the use of boars from elite breeder herds. Interest in all types of selection programs has been dampened by the good results that accompany crossbreeding in swine. In an AI program, the best boars from tested herds could be used widely in commercial herds, thus raising the genetic merit of all herds. Even for such a highly heritable trait as rate of gain, the increase in selection differential accruing through AI would speed genetic progress, as opposed to a closed herd system. Where progeny testing or family selection is required, as in weaning weight of litter or carcass merit, artificial service offers even greater promise for improvement than other systems of selection.

Certain nongenetic advantages accompany artificial service in swine. An important advantage is the reduction in risk of spreading virus pneumonia and other diseases among small swine enterprises when stud boars are shifted in use from farm to farm. A second advantage is that occasionally meritorious boars cannot be used on small females other than through artificial service.

It has been suggested that the evaluation of boars may be made more accurate by inseminating sows with mixed semen so that the progeny of boars can be compared on a within-litter basis. This would circumvent problems raised by maternal effects.

CURRENT STATUS IN SHEEP

No exact statistics are available on the number of sheep bred artificially in the United States, but the number is surely very small. The situation contrasts with the 33 million sheep bred artificially in

the USSR in 1959. The lack of interest in AI is largely due to the same reasons outlined for swine and beef cattle. Most sheep are produced on the western ranges where their density per square mile is very low. This low density increases AI costs if professional inseminators are employed, and it increases the difficulty of adequate heat detection.

Blackwell (3) pointed out that the low monetary value of a ewe, compared with that of a dairy cow, makes sheep AI costly. The annual cost of service for a cow is 2 to 4 percent of her value. In terms of a ewe, this would be only $0.60 to $1.20. It is questionable whether semen alone can be furnished for this amount. The fixed costs associated with a ram stud may not be greatly different from that for a dairy stud, except for the initial cost of animals.

An added problem, from the standpoint of stud operation and use of professional inseminators, is the seasonality of breeding. This may be a serious drawback unless both dairy and sheep production exist in the same area so that the one organization could service both kinds of animals. Such situations are not common in the United States.

As in other classes of livestock, performance testing is quite minor in sheep production. If AI becomes economically practical, increased testing would be required to effectively utilize it. In addition, as pointed out by Blackwell (3), the breeding value of rams for total merit would have to be determined with greater precision than in closed-herd systems. Progeny testing or family selection would be required for such traits of economic importance as weaning weight and ewe productivity. It may be expected that proper evaluation of rams for AI would require measuring daughters or paternal sisters of a ram in many different flocks. It seems unlikely that measurement of the ram's transmitting ability for fleece weight or rate of gain at a single location would be adequate for accurate selection. Ram evaluation therefore becomes a more complex and costly proposition.

The solution of many biological problems would make artificial service of sheep more practical than it is now. To date, the general experience with stored (chilled) and frozen semen has been unsatisfactory, thus necessitating daily collection and immediate use. First, Severinge, and Henneman (12) compared insemination by use of frozen semen with service by fresh semen in three trials. The lambing rates were 17 percent, 30 percent, and 0 percent for frozen semen and 64 percent, 66 percent, and 33 percent for fresh semen. Dauzier (6) reported that conception rates were drastically reduced where semen was stored for 12 to 24 hours at 2° to 4° C.

Conception rates obtained with fresh semen appear to be adequate, although improvements in technique and methods will probably yield better results. If an adequate volume of semen is deposited in the cervix, a conception rate of 55 to 60 percent can be anticipated. Detection of estrus can be done in two ways: (1) Hand-teasing with vasectomized rams or (2) running vasectomised rams continually with the flock. The latter is much the simplest way, especially if the brisket of the teaser is liberally painted with some readily scourable colored branding fluid. Ewes observed with clearly defined traces of the paint in the morning may be inseminated that same day at mid-estrus. In either case, close observation of the ewe is required.

Considerable research is being devoted to estrus control in the ewe, although mainly in Australia. Emmens and Robinson (9) concluded that estrus may be synchronized by treatment with progesterone injected every 1 or 2 days for 16 days. Evans, Dutt, and Simpson (10) reported satisfactory control of estrus and ovulation by daily injection of a progesterone compound for 14 days. Ninety-five percent of the treated ewes came in estrus within 2 to 5 days posttreatment. Thus far, however, fertility and lambing rates following hormonal treatment have been very low.

In summary, the present physical and economic structure of the sheep industry is not conducive to the economical use of artificial insemination. The development of estrus control procedures that allow acceptable conception rates would greatly stimulate the adoption of AI. In general, the operational structure that favors the use of artificial service is characterized by large flocks of ewes and a number of specialized herdsmen attached to each ranch. This would allow one or more workers to become skilled in the technique of artificial insemination. If estrus control is perfected, the use of groups of professional inseminators during the breeding season might become economically feasible.

CURRENT STATUS IN POULTRY

At the present time, the only major commercial application of artificial insemination in fowl is with the Broad Breasted turkey (19). Because of the size and conformation of these birds, natural matings are marked by low fertility. With AI the fertility rate is much improved. An estimated 4 million turkeys are mated artificially each year. This is an interesting development of artificial selection that would tend to be eliminated in nature.

In other poultry, artificial insemination is largely limited to such research applications as the production of interspecific crosses. It is also used in studies of poultry reproduction problems.

A number of factors are involved in the negligible usage of poultry AI. These are partly biological and partly economic. The egg and broiler industries in the United States are dominated by very large production units, which in many cases produce their own chicks. Also, less attention is given to selection among individual birds than is the case in large animals. Selection of breeding stock is largely a matter of selection among genetic groups (family selection) and on the basis of line-cross performance. This is especially true in broiler production where cross-breeding is important. Performance testing is practiced for egg-laying strains, but replicate entries for different test locations are obtained by random sampling of hatching eggs from the strain as a whole. Because individual differences within groups are ignored, the use of artificial insemination has much less utility than it would have otherwise.

Artificial insemination of hens is performed most conveniently under cage conditions. The laying batteries should have an easily moveable front so that the bird can be pulled partly out of the cage. Moultrie (20) reported that in-cage insemination increased the rate of servicing by 40 birds per hour. The effect of the handling on birds during insemination was also investigated by Moultrie (20). He found no disturbance to production.

The necessity of handling each individual breeder hen for the insemination adds another expensive labor charge in an industry that is already characterized by low profit margins per bird. This problem is lessened by the fact that one insemination fertilizes several eggs over a period of time. The usual recommendation is that hens be inseminated once every 7 days and turkeys once every 15 days until midbreeding season and weekly thereafter.

Biological problems are related to the storage and dilution of fresh semen and the fertilizing capacity of deep-frozen fowl sperm. Little progress has been made to elucidate the fundamental metabolic processes of avian sperm activity. At present the usual practice is to use fowl semen in undiluted form within one-half hour after collection. Carter et al. (4) and McCartney et al. (19) found a sharp drop in fertility when turkey semen was stored at either 10°C. or 15° C. for only 2 hours. The problem is more critical in poultry than in cattle because the sperm must have capacity to fertilize eggs for a period of several days. Progress has been made in the storage of fowl semen, according to Wilcox and Shaffner (35). Wilcox (34) obtained reasonable fertility from sperm diluted by a factor of 10 and stored at 10° C.

The technique of storing fowl semen at subzero temperatures has yet to be solved. Some English work has shown that on rare occasions live chicks can be produced from sperm that has been frozen for as long

as 33 days. Shaffner (27) reported that fertility as high as 40 percent was achieved with samples of deep-frozen semen. Thus, there is promise that further research may produce satisfactory freezing techniques.

There seems little likelihood that artificial insemination will ever be a major factor in poultry breeding except to overcome the infertility of natural mating in turkeys or in crossing the heavy breeds of poultry with the light breeds. Moultrie (20) suggested that AI could be used on broiler-stock hens that exhibit low egg production when kept on the floor compared to the production of hens in cage housing. As a rule, performance of hens is superior when they are kept on the floor to that when they are kept in cages.

Artificial insemination may also be used where natural mating suffers seasonal declines in fertility. It is used in some cases in the development of inbred lines. The solution of various biological problems associated with artificial insemination is not likely to greatly expand its use in the production of hatching eggs.

CURRENT STATUS IN HORSES

Horse production in the United States is almost entirely for purposes of sport and pleasure. However, this population is increasing to some extent. There is a certain market for horse AI because the number of mares per owner is usually very small. Horse AI is handled almost exclusively by veterinarians. There is only one report of artificial service of horses by livestock studs (28). According to foreign reports, especially from Russia and mainland China, horse AI is feasible on a large scale. Conception rates of 60 percent have been reported from these places.

In general, semen of the horse is quite delicate and is difficult to store for extended periods of time. This probably is due to the relatively weak lipoid capsule of the sperm cell. Low-temperature storage has received some attention in research studies. There are reports of semen having been stored at -79° C. for 30 days retaining some of its fertilizing capacity. Solomon (28) reported that conception rates of 70 percent were obtained from semen of stallions, ponies, and jacks frozen in liquid nitrogen.

If the procedure for freezing semen can be refined, horse AI probably will expand considerably in the United States. Commercial fertility rates may be low with either frozen or fresh semen because of the difficulty of detecting estrus, particularly among inexperienced owners. There is no likelihood that horse AI will ever be more than a means of settling mares because there are no quantitative standards for stallion selection.

SUMMARY

Artificial insemination has been adopted to a significant extent only in dairy cattle and turkeys in the United States. Currently, about 4,000,000 turkey hens are inseminated artificially, or over 95 percent of the breeder hen population. In 1966, 6,413,453 cows were bred artificially, representing about 48 percent of the entire dairy cattle population. Practical experience and research studies indicate that the genetic progress attributable to dairy AI has been much less than is possible. The disappointing results are due to failure to implement sound programs for selecting and testing sires. Many bulls with large negative proofs have been used heavily in AI. Recent trends, including young sire testing programs, indicate that genetic progress will be more substantial in the future than in the past.

The application of artificial insemination to species other than dairy livestock has been hindered by the relative costs of such service, including the required additional handling and observation of females. The perfection of commercially practical methods for controlling estrus and of deep-freezing semen would greatly accelerate the adoption of AI for animals other than dairy cattle.

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